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Assisted pressure control ventilation via a mini-tracheostomy tube for postoperative respiratory management of lung cancer patients

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Assisted pressure control ventilation (PCV) via a min-tracheostomy tube (MTT) was conducted to improve gas exchange and reduce the work of breathing of lung cancer patients after surgery.

Thirty-two patients with lung cancer underwent lobectomy and were managed postoperatively by assisted PCV via an MTT. On the basis of a simulation study using a lung model for clinical use, we set the inspiratory pressure to 20 cmH_2O and inspiratory time to 1.0 sec to produce a 450-ml supported volume via the MTT per breath. The blood gases and respiratory rate of each patient were measured under three sets of conditions: PCV via an MTT transtracheal oxygenation (TTO) via an MTT and a Venturi face mask with the same FiO_2. After PCV via an MTT overnight, the blood gases in the room air were measured 2.5 h after withdrawing PCV. In order to determine the effect of PCV via an MTT on gas exchange after PCV withdrawal, 32 other age and sex-matched lung cancer patients, who had undergone lobectomy and oxygenation via a face mask alone after surgery, were used as historical controls.

The simulation study showed that the ventilated volume provided by assisted PCV via an MTT was about half that provided via a conventional endotracheal tube, even in the presence of air leakage. The clinical application showed that the ventilated volume obtained with the PCV via an MTT was significantly higher than that with spontaneous breathing ($P<0.001$). PCV via an MTT increased the PaO_2 and reduced both the $PaCO_2$ and respiratory rate significantly in comparison with TTO via an MTT and a face mask ($P<0.001$). After PCV withdrawal the morning after surgery, the PaO_2 of the PCV group was significantly higher than that of the historical controls ($P<0.001$). No postoperative pulmonary complications were observed in either the PCV or the control groups, however. In addition, no complications or morbidity were seen related to either MTT insertion or PCV via an MTT.

Assisted PVC via an MTT increased the tidal volume, improved the gas exchange, reduced the respiratory rate by providing adequate ventilatory support and increased the PaO_2, even after withdrawal following lung surgery. Even though we did not observe any benefit of clinical outcome with PCV via an MTT in the present study, this procedure appears to be a potentially useful respiratory management modality for patients with high risk of postoperative pulmonary complications.

Key words: pressure control ventilation; minitracheostomy tube; positive airway pressure; postoperative pulmonary complications.

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Introduction

After lung resection, pulmonary gas exchange deteriorates due to the loss of functional parenchyma, respiratory drive depression by narcotics and microatelectasis due to sputum retention during surgery. Postoperative continuous positive airway pressure (CPAP) administered by a facial or nasal mask restores the functional residual capacity to preoperative values, improves oxygenation, spares inspiratory muscle work and prevents and treats pulmonary atelectasis (1,2). Bilevel positive airway pressure (BiPAP System; Respironics Inc; Murrysville, PA, U.S.A.), which combines pressure support ventilation (PSV) and positive end-expiratory pressure (PEEP), has been used to improve gas exchange in patients with different forms of respiratory failure (3–5) and has also been tried for preventing and treating pulmonary atelectasis after upper abdominal and lung surgery (6,7). However, CPAP and BiPAP require the patient's participation and can only be administered for a limited time because of the oppressive sensation of the facial or nasal mask.

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Tracheal ventilation via a mini-tracheostomy tube (MTT) has been used as an emergency life saving measure when tracheal intubation is rendered unfeasible by total airway obstruction. The ventilatory modes generally used in such situations are jet ventilation, oxygen flushing or a standard anesthesia circle system with high pressure (8). Gregoretti *et al.* reported a patient with flail chest trauma who was treated successfully using pressure control ventilation (PCV) via an MTT (9). Since 1988, we have used MTTs regularly to treat postoperative sputum retention in order to prevent atelectasis and pneumonia after lung cancer surgery. Now, we also use MTTs to provide overnight ventilatory support after lung resection in order to improve gas exchange and reduce the work of breathing. We conducted a simulation study of ventilatory support via an MTT using a lung model to determine the optimal ventilator set-up for clinical use and present the results of its use in patients undergoing lung surgery.

Materials and methods

SIMULATION STUDY

The airway resistance of an MTT [internal diameter (ID), 4 mm; Minitrach II, Portex Ltd., Hythe, Kent, U.K.] and an endotracheal tube (ID, 8 mm) was examined by measuring the airway pressures at air flow rates of 20–80 $1\ \mathrm{min}^{-1}$.

The lung model was the two-compartment bellows system (Dual Adult TTL, Michigan Instruments, Grand Rapids, MI, U.S.A.) developed by Katz *et al.* (10). One compartment was connected in sequence to the test ventilator and the other to the ventilator ('muscle' ventilator) used to represent the patient's breathing (Fig. 1). Both ventilators were Bear 1000 ventilators (Bear Medical Systems. Inc., Riverside CA, U.S.A.) The muscle ventilator was used to inflate one compartment, which displaced the other compartment with a lift bar, simulating the function of the respiratory muscles. As the other compartment expanded, the resultant negative pressure was transmitted to the test ventilator through the MTT. The lung model's air leakage adapter (2 mm in diameter) was used to simulate clinical air leakage. An endotracheal tube (ID, 8 mm) was used instead of the MTT in the control experiment. The lung compliance of both compartments was set to 50 ml $\mathrm{cmH_2O}^{-1}$, the volume of the muscle ventilator to 100 ml, the respiratory rate to 6 min^{-1} and the air flow rate 30 l min^{-1}. The test ventilator was set to PCV mode with the inspiratory time fixed at 1.0 sec, respiratory rate at 0 min^{-1}, sensitivity at -1 $\mathrm{cmH_2O}$ and PEEP to 0 $\mathrm{cmH_2O}$. The inspiratory pressure was varied between 10 and 25 $\mathrm{cmH_2O}$ and the alveolar pressure of the lung model and inspiratory volume of the test ventilator were measured using a calibration analyser (RT-200, Timester, St. Louis, MO, U.S.A.). The ventilated volume was read from the graduations of the lung model and the leakage volume from the leakage adapter was calculated by subtracting the ventilated volume from the inspired volume.

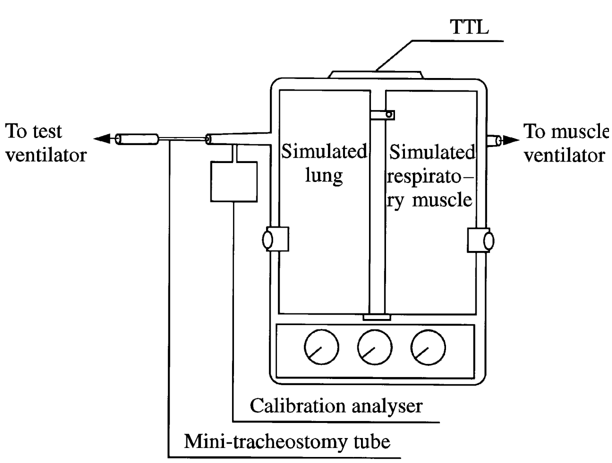

FIG. 1. Lung model using a training test lung (TTL) to simulate spontaneous breathing.

SUBJECTS

From January 1997 to January 1998, 35 lung cancer patients underwent lobectomy. All but three who had postoperative air leakage from the lung, had an MTT inserted after surgery and were managed by assisted PCV via the MTT in intensive care unit (ICU) until the next morning. Since 1988, we have regularly used MTTs to treat postoperative sputum retention in lung cancer patients. We informed the patients participating in this study about the use of an MTT for ventilatory support overnight in addition to its use to treat postoperative sputum retention and obtained written consent from them all. The subjects comprised 25 men and seven women with a mean age of 63 years (range: 42–75). They were intubated with a double-lumen tube and standard anesthesia with inhaled isoflurane, nitrous oxide and oxygen and intravenous pancronium bromide was administered. When the pleural space was opened, single-lung ventilation was used. On completion of surgery, the patients were extubated and, using a guide wire, an MTT (ID, 4 mm) was inserted under local anesthesia via the cricothyroid membrane. Epidural morphine (3 mg 24 h^{-1}) was started when anesthesia was started and continued for 3 days postoperatively.

In order to determine the effect of PCV via an MTT on pulmonary gas exchange after PCV withdrawal, 32 other lung cancer patients who had undergone lobectomy, MTT intubation and postoperative respiratory care with oxygenation via a Venturi face mask alone were used as historical controls. They were selected consecutively from 131 patients who underwent lung cancer surgery between 1993 and 1996 to match the sexes and ages (± 5 years) of those in the PCV group (Table 1). The preoperative pulmonary function, blood gas analysis results and sites of lobectomy of the two groups were not significantly different. All the patients underwent similar general anesthetic procedures and epidural anesthesia with morphine and were intubated with a double-lumen endotracheal tube to enable selective contralateral ventilation and lobectomy to be performed.

TABLE 1. Patients' profiles

Group	PCV via an MTT	Controls (face-mask)
Male/female	25/7	25/7
Age (years)	63 ± 9	60 ± 9
Preoperative pulmonary function		
VC (l)	3.0 ± 0.7	3.2 ± 0.8
%VC	95 ± 17	103 ± 17
FEV_1 (l)	2.2 ± 0.6	2.4 ± 0.6
%FEV_1	74 ± 9	78 ± 8
Preoperative blood gas analysis		
PaO_2 (torr)	84 ± 9	85 ± 11
$PaCO_2$ (torr)	42 ± 3	43 ± 2
Sites of lobectomy		
RUL	11	11
RLL	9	<9
RML + RLL	2	3
LUL	7	6
LLL	3	3

PCV: pressure control ventilation; MTT: minitracheostomy tube; BGA: blood gas analysis; VC: vital capacity; FEV_1: forced expiratory volume in 1 sec; RUL: right upper lobe; RLL: right lower lobe; RML: right middle lobe; LUL: left upper lobe; LLL: left lower lobe.

An MTT was inserted in each control subject to treat postoperative sputum retention, but not to provide postoperative ventilatory support. The blood gases while spontaneously breathing room air were measured the next morning 30 min after withdrawing the face mask.

STUDY DESIGN

The time schedule of the study is shown in Fig. 2. After entering the ICU, the patients were oxygenated via a Venturi face mask (oxygen flow rate: 8 l min^{-1}; FiO_2: 0.4; Unimed Co., Armagh, Northern Ireland) and transtracheal ventilation via an MTT by assisted PCV using a Bear 1000 ventilator (Fig. 3). The assisted PCV conditions were set as follows: respiratory rate, 0 min^{-1}; pressure, 20 cmH_2O; inspiratory time, 1·0 sec; PEEP, 0 cmH_2O; and FiO_2, 0·4, the conditions which provided a 450-ml supported volume via the MTT in the simulation study. When the haemodynamics, consciousness and pain had stabilized ($2{\cdot}3 \pm 0{\cdot}4$ h after extubation), the volumes expired via the MTT were read off the ventilator display and the expired volume via the mouth was measured using a spirometer. The tidal volume under the conditions of PCV via an MTT was calculated from the total of the two expired volumes and the average value of 20 breaths was determined. The average tidal volume of 20 breaths while breathing spontaneously with the MTT closed was measured using a spirometer. Assisted PCV via the MTT was restarted and the respiratory rate, blood gases, supported volume via the MTT and haemodynamics were measured 30 min later (① in Fig. 2). The inspiratory pressure was changed to

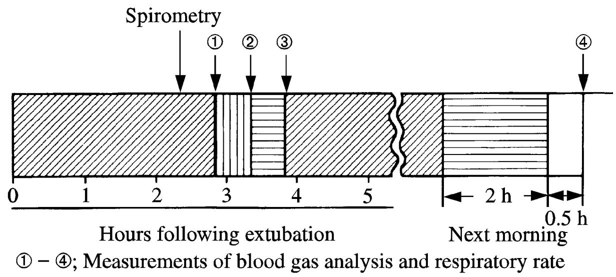

FIG. 2. Time schedule of the study.

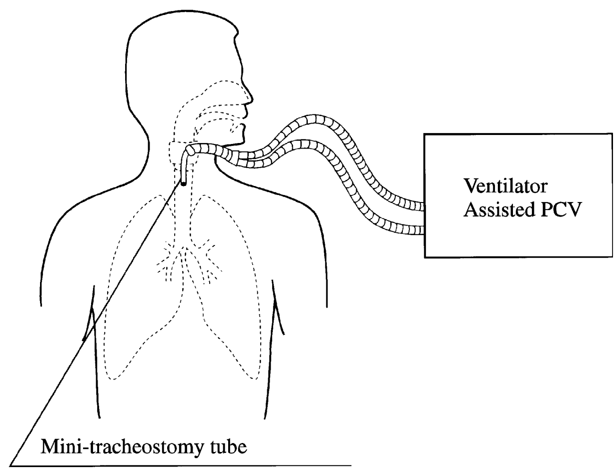

FIG. 3. Assisted pressure control ventilation via a minitracheostomy tube.

0 cmH_2O, i.e. transtracheal oxygenation (TTO) given by oxygen flow through the ventilator (FiO_2: 0·4), and the same parameters were measured 30 min later (② in Fig. 2). Then, the patients were oxygenated via a Venturi face mask alone (oxygen flow rate: 8 l min^{-1}: FiO_2: 0·4) with the MTT closed and the same parameters were measured 30 min later (③ in Fig. 2). The FiO_2 under each set of conditions was maintained at 0.4. Finally, the patients underwent assisted PCV via an MTT with face mask oxygenation again overnight and 2·5 h after PCV withdrawal the next morning, the blood gases while spontaneously breathing room air with the MTT closed were measured (④ in Fig. 2).

STATISTICAL ANALYSIS

The differences between the blood gas and respiratory rate values under each set of respiratory conditions were analysed for significance using the two-tailed Student's *t*-test for paired values. The differences between the blood gas values the morning after surgery of the PCV and control groups were analysed using the two-tailed Student's t-test. Differences at $P<0{\cdot}05$ were considered significant. All the values in the text and tables are means ± SD.

Results

SIMULATION STUDY

The airway resistance of the endotracheal tube changed from 1·6 to 4·9 $cmH_2O\ l^{-1}sec^{-1}$ as the air flow rate was varied from 20–80 l/min and the MTT resistance increased from 30–98 $cmH_2O\ l^{-1}sec^{-1}$. At every flow rate tested, the MTT resistance was about 20 times higher than that of the endotracheal tube.

The alveolar pressure, inspired volume and ventilated volume via the MTT without air leakage were about 50% of those via the endotracheal tube (Table 2).The inspired volume provided by PCV via an MTT with air leakage was higher than that provided by PVC via an MTT without air leakage, but the alveolar pressures and ventilated volumes under all the conditions tested were similar. Under the conditions of a set pressure of 20 cmH_2O and an inspiratory time of 1·0 sec, the ventilator provided a ventilated volume of 450-ml via an MTT with or without air leakage.

CLINICAL USE

Assisted PCV via an MTT responded to each patient's inspiration and provided adequate ventilatory support and virtually no air leakage from the patients' mouths occurred during the procedure. The mean tidal volume was 571 ± 55 ml during assisted PCV via an MTT, which was significantly higher than that during spontaneous breathing with the MTT closed 467–42 ml, ($P<0{\cdot}001$). The mean supported volume provided by PCV via an MTT, according to the ventilator's display, was 451 ± 18 ml, which was similar to that provided by MTT without air leakage in the simulation study. PCV via an MTT did not change the heart rate, systemic blood pressure or diastolic blood pressure, the patients' speech was not disturbed, the patients did not complain of discomfort during the procedure and it did not induce pleural air leakage. Chest X-rays one day after surgery revealed no pneumothorax or atelectasis. There were no complications with MTT insertion, such as surgical emphysema, haemorrhage and misdisplacement.

The mean PaO_2 distribution values [Fig. 4(a)] were 157·2 ± 24·5 torr for PCV via an MTT, 129·3 ± 26·1 torr for TTO via an MTT and 133·8 ± 32·3 torr with a face mask. PCV via an MTT resulted in a significantly higher PaO_2 than TTO via an MTT or a face mask ($P<0{\cdot}001$) and the PaO_2 values with the latter two procedure were not significantly different.

The mean $PaCO_2$ distribution values [Fig. 4(b)] were 40·1 ± 4·5 torr for PCV via an MTT, 44·7 ± 4·1 torr for TTO via an MTT and 45·4 ± 4·2 torr with a face mask. PCV via an MTT resulted in a significantly lower $PaCO_2$ than TTO via an MTT or face mask ($P<0{\cdot}001$) and the $PaCO_2$ values with the latter two procedures were not significantly different.

The mean respiratory rate distribution values [Fig. 4(c)] were 16·4 ± 3·4 min^{-1} for PCV via an MTT, 19·9 ± 3·4 min^{-1} for TTO via an MTT and 20·3 ± 4·2 min^{-1} with a face mask. The respiratory rates with PCV via an MTT were significantly lower than that with TTO via an MTT ($P<0{\cdot}001$) or a face mask ($P<0{\cdot}001$) and the respiratory rates with the latter two procedures were not significantly different.

The mean PaO_2 values while breathing room air the next morning of the groups on PCV via an MTT and oxygenation only via a face mask were 72·6 ± 8·8 and 65·9 ± 6·2 torr, respectively (Fig. 5). The PaO_2 of the PCV group was significantly higher than that of the control

TABLE. 2. Alveolar pressure, inspired volume and ventilated volume via endotracheal tube and a minitracheostomy tube with and without air leakage with the inspiratory time set at 1.0 sec

Endotracheal tube				
Set pressure (cmH_2O)	25	20	15	10
Alveolar pressure (cmH_2O)	25.7	21.8	16.6	11.6
Inspired volume (1)	1.19	0.99	0.74	0.48
Ventilated volume (1)	1.23	1.0	0.8	0.5
Minitracheostomy tube without air leakage				
Set pressure (cmH_2O)	25	20	15	10
Alveolar pressure (cmH_2O)	12.3	11.4	9.8	7.8
Inspired volume (1)	0.52	0.45	0.37	0.28
Ventilated volume (1)	0.52	0.45	0.4	0.3
Minitracheostomy tube with air leakage				
Set pressure (cmH_2O)	25	20	15	10
Alveolar pressure (cmH_2O)	11.8	10.5	9.4	7.3
Inspired volume (1)	0.77	0.68	0.57	0.44
Ventilated volume (1)	0.5	0.47	0.38	0.3
Leakage volume (1)	0.27	0.21	0.19	0.14

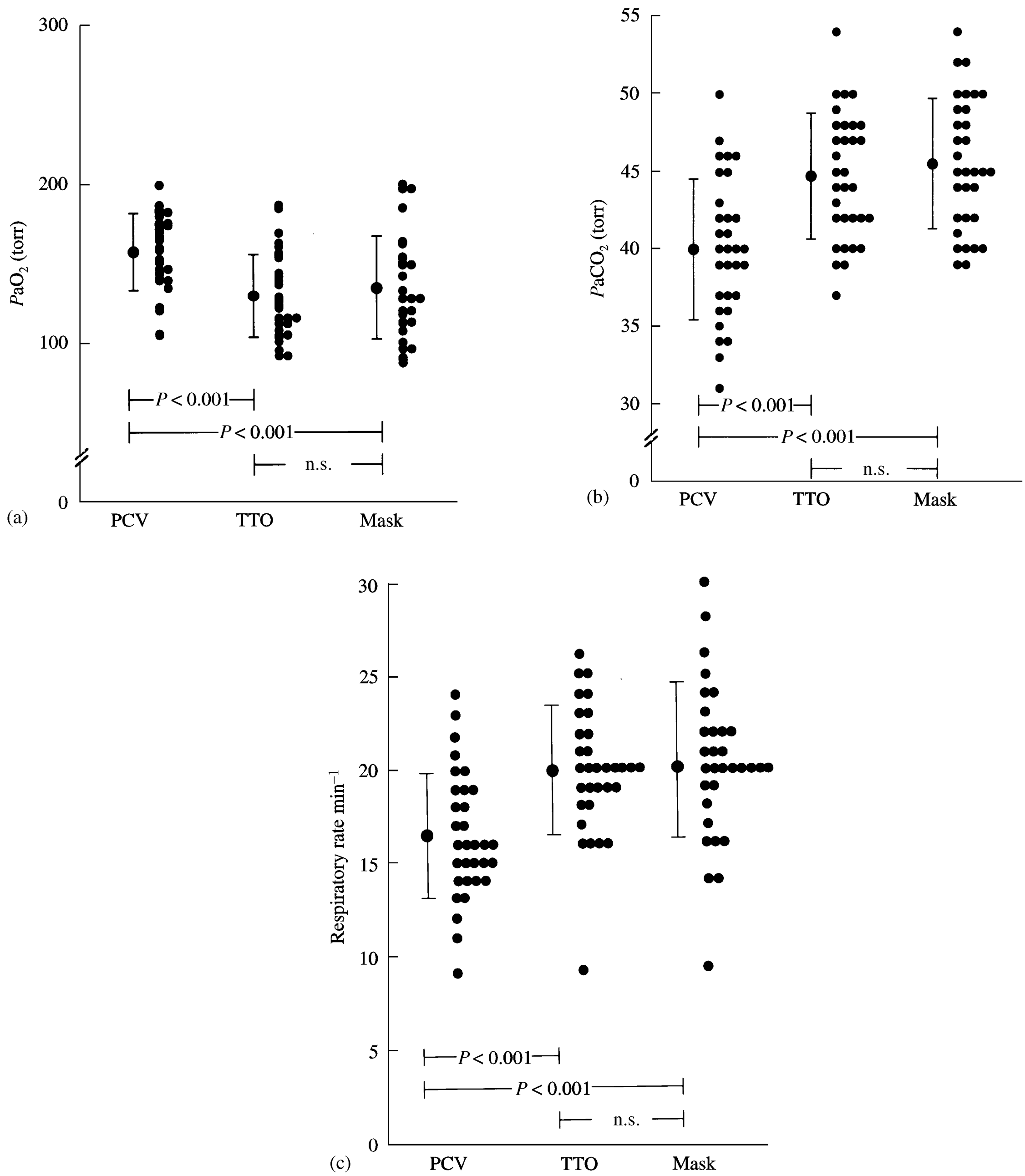

FIG. 4. (a) PaO_2 , (b) PaO_2 and (c) respiratory rate distributions under the conditions of PCV via an MTT, TTO via an MTT, and a face mask. (For abbreviations see text.)

group, even after PCV withdrawal ($P < 0{\cdot}001$). The mean $PaCO_2$ values of the PCV and control groups were $44{\cdot}8 \pm 3{\cdot}0$ and $46{\cdot}3 \pm 3{\cdot}6$ torr, respectively, and were not significantly different. No postoperative pulmonary complications were observed in either the PCV or the control groups, however.

Discussion

Generally, MTTs are used for sputum drainage in patients with a restricted ability to expectorate. We use MTTs routinely to treat sputum retention after lung cancer surgery. MTTs have also been used for transtracheal ventilation for emergency life saving when tracheal intubation is unfeasible. In this study, we used an MTT to provide ventilatory support to improve gas exchange and reduce the work of breathing in addition to treating sputum retention after lung surgery. We used assisted PCV for the following reasons: 1. adequate spontaneous postoperative breathing did not require mandatory ventilation and pressure support for spontaneous breathing was sufficient; 2. although pressure support ventilation (PSV) can respond to a patient's inspiration, the flow threshold that triggers

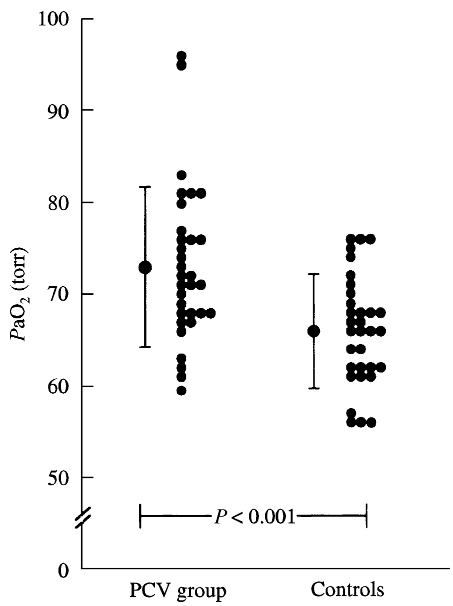

FIG. 5. PaO_2 distributions of the pressure control ventilation (PCV) and control groups the morning after surgery.

expiration may not be reached because the volume expired via an MTT is too low, resulting in prolonged inspiration known as 'inspiratory hang-up'; and 3. assisted PCV responds to a patient's inspiration in much the same way as PSV and can set an inspiration time, resulting in regular ventilatory support via the MTT for spontaneous breathing.

The simulation study using a lung model showed that assisted PCV via an MTT yielded an adequate ventilated volume despite the high MTT airway resistance. Even though the airway resistance of the MTT used was much higher than that of a conventional endotracheal tube, the ventilated volumes achieved with PCV via an MTT without air leakage were maintained at about 50% of the volume provided by an endotracheal tube. As PCV via an MTT may be accompanied by air leakage from the mouth or nose during inspiration when it is used clinically, we also examined the alveolar pressure and ventilated volume using the leak adapter of the lung model. The results showed that PCV via an MTT with the leak adapter yielded a similar alveolar pressure and ventilated volume as the procedure without air leakage, because the PCV system compensated for air leakage by increasing the air flow. Therefore, on the basis of the results of the simulation study, we set the inspiratory pressure to 20 cmH_2O and the inspiration time to 1.0 sec for clinical use in order to produce a 450-ml supported volume via the MTT using a ventilator, because this volume is adequate after lung resection. The assisted PCV via an MTT significantly increased the ventilated volume and reduced the respiratory rate in comparison with spontaneous breathing. Therefore, we surmise that the patients could inspire with less work of breathing on PCV via an MTT than they could when breathing spontaneously. In clinical use, PCV via an MTT yielded a mean supported volume of 451 ml, which was similar to the value under the conditions of an MTT without air leakage in the simulation study. The patients showed virtually no air leakage from their mouths during the procedure. Therefore, we consider that PCV via an MTT under the conditions we used (a pressure of 20 cmH_2O and an inspiratory time of 1.0 sec) did not provide an excessive supported volume for patients after lung surgery.

Ventilation with PSV has been reported to increase the PaO_2 by enlarging the alveoli and recruiting zones of alveolar collapse, resulting in better ventilation–perfusion matching (11–13), and PSV reduced both the $PaCO_2$ and respiratory rate while reducing the work of breathing and increasing the ventilated volume (14,15). The assisted PCV technique used in our study provided similar ventilatory support to PSV, because it provided inspiratory flow in one second for each spontaneous inspiration. In clinical use, assisted PCV via an MTT increased the ventilated volume and resulted in significantly higher PaO_2 values and significantly lower $PaCO_2$ values and respiratory rates than TTO via an MTT or a face mask, presumably as a result of mechanisms similar to those with PSV described above. Although we did not actually measure the work of breathing, we surmise that PCV via an MTT reduced the work of breathing in the same way as does PSV, because gas exchange improved and the respiratory rate decreased with PCV via an MTT.

We verified that the PaO_2 2.5 h after PCV withdrawal the morning after surgery was significantly higher than that of the control subjects. This finding indicates that PCV via an MTT overnight opened previously closed lung units during the procedure and they remained open after PCV withdrawal, i.e. it treated postoperative lung microatelectasis resulting in better ventilation–perfusion matching.

BiPAP has been tried to prevent and treat pulmonary atelectasis after upper abdominal and lung surgery (6,7). PCV via an MTT, although far from completely non-invasive, has the following advantages over BiPAP: 1. BiPAP requires the patient's participation and the time it can be used for is limited because of the oppressive sensation of the nasal mask, nasal cavity irritation due to the air flow and eye irritation due to air leakage, whereas PCV via an MTT can be used for long periods without discomfort; 2. PCV via an MTT reduces the ventilatory dead space, whereas BiPAP may increase the dead space to tidal volume ratio (16); and 3. tracheal suction via an MTT to remove retained sputum can be carried out easily and also helps to prevent postoperative pulmonary atelectasis and pneumonia. Furthermore, PCV via an MTT did not interfere with the patients' speech. Although complications with MTT insertion, such as surgical emphysema, haemorrhage and misdisplacement, have been reported (17), they are very rare and we have never experienced them when using a guide wire technique. Therefore, apart from the necessity for a mini-tracheostomy, PCV via an MTT appears to present no particular disadvantages.

In summary, we found that assisted PCV via an MTT provided adequate ventilatory support, improved gas exchange both during the procedure and after its withdrawal and reduced the respiratory rate without adverse side effects following lung cancer surgery. Although we observed no postoperative pulmonary complications in either the PCV or control groups, we believe that this procedure appears to be a potentially useful respiratory management modality for patients with high risk of postoperative pulmonary complications after lung surgery. A prospective study on patients at high risk of postoperative pulmonary complications should be conducted.

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